Electric vehicle and plug-in hybrid energy efficiency and life cycle emissions

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Introduction

Mobility is an important basis for many economic and private activities and thus a crucial part of our life. In many industrialised countries, the demand for mobility is mostly covered by road traffic. Modern vehicles and a well developed network of roads allow for a high degree of individual mobility. However, this mobility also leads to substantial environmental problems: In Germany, for instance, transport is responsible for over 20% of the energy consumption and CO_2 emissions. The majority of these emissions are due to road traffic, which in turn is dominated by passenger transport (see Figure 1). Though CO_2 emissions from road traffic and especially passenger cars are slightly decreasing in Germany since about 2000, this decrease is still limited. The associated consumption of fossil resources by road traffic not only contributes significantly to climate relevant CO_2 emissions, but also faces limited resources and leads to political dependencies.

Additionally, road traffic is a cause of noise and emits various pollutants with direct negative effects on human health. For pollutants such as carbon monoxide (CO) and hydro carbons (HC), already substantial improvements have been achieved in the past. In respect to other substances such as diesel particles and nitrogen oxides, road traffic - despite a considerable emission decrease in recent years (see Figure 1) - still makes a relevant contribution to current exceedances of air quality limit values for PM10 and NO_2.

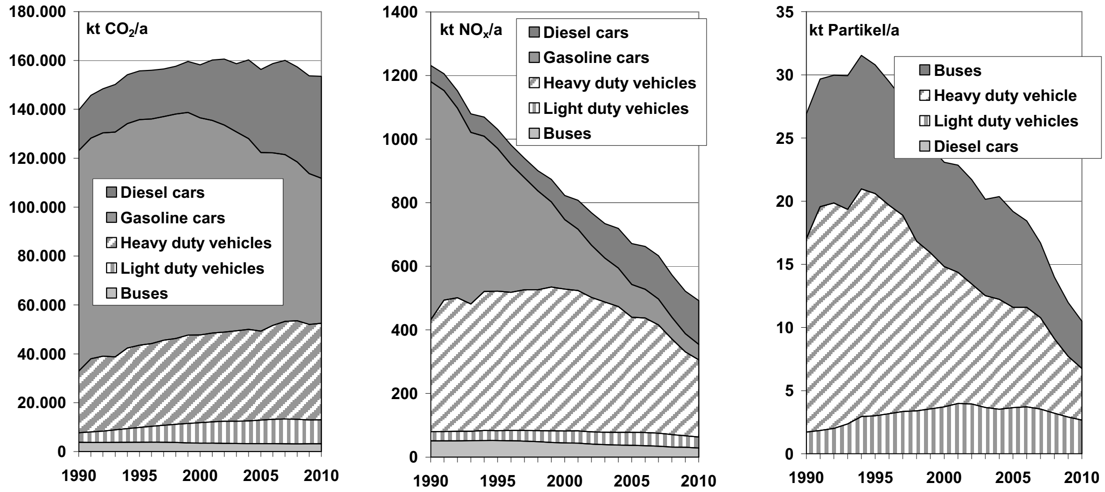


Figure 1: Direct CO_2, NOx and particle emissions of road traffic in Germany (Source : TREMOD (Knörr, 2010))

This calls for an improvement of the environmental profile of road traffic. For vehicles with conventional combustion engines, a further tightening of the emission legislation as well as new limit values for carbon dioxide are already on their way on a European level. These strategies, however, can only partly solve the environmental problems of transport. Another potential pillar of an 'environmental strategy for road traffic' is electric mobility: Electric vehicles have quiet engines, are locally emission free and allow for the use of many (also renewable) energy sources in road traffic - which so far could not be used.

Electric mobility has always been the first choice whereever electricity has been available: For long distances in trains, for short distances in trams or subways and even within buildings in elevators and escalators. In Germany, electric local and long distance trains have consumed about 9 TWh of electricity in 2007 - 1.5% of the gross electricity consumption. For road traffic, however, there has been the problem of mobile storage of electricity. Batteries have been heavy and had a low energy density, electric vehicles thus had a very short driving range. Now, new technological developments, triggered also by consumer electronics such as laptops and mobile phones, have lead to a considerable improvement of the performance of batteries. Electric vehicles are therefore considered as a serious alternative for conventional vehicles.

In order to improve the environmental profile of road traffic, advantages and disadvantages of electric vehicles have to be identified and addressed at an early stage. This calls for a thorough environmental assessment of electric vehicles, which covers the full life cycle, from vehicle production via vehicle use and electricity generation to disposal and/or recycling. A previous screening LCA by IFEU (Pehnt et al., 2009) showed that the highest contribution to life-cycle emissions comes from the use phase. These emissions are mainly influenced by the energy efficiency of electric vehicles and the electricity generation. Both aspects are now therefore analysed in more detail in this paper.

First, a realistic assessment of electric vehicle energy consumption is presented, which is based on realistic speed profiles and also considers auxiliary consumers. Afterwards, electricity generation for charging of electric vehicles is analysed, taking into account that the mix of power plants for charging is a function of economic framework conditions in the energy sector. Finally, life cycle results are presented and discussed.

The results published in this paper are based on various IFEU research activities, including the environmental assessment of various electric mobility pilot projects, and will be further refined in the future. In particular, a more detailed balance of the production process, empirical data on electricity consumption patterns, as well as an energy economic modelling of the interactions with the electricity sector will be included.

Electric vehicle energy efficiency

The specific energy consumption of electric vehicles is an important parameter in the assessment of life-cycle emissions. Energy efficiency not only influences the absolute energy consumption vehicles and thus the life cycle balance. Energy efficiency also has a considerable impact on the electric driving range or the required battery capacity which in turn influences vehicle weight and costs. Furthermore, conventional vehicles are expected to improve their environmental performance in the future and electric vehicles will need to further enhance their energy efficiency to keep up with this development. This calls for a thorough analysis of the energy consumption of electric vehicles under realistic conditions.

So far, only few measured data are available of which some are only measured in standardised cycles (e.g. NEDC) and thus do not represent the energy consumption in realistic use profiles or take into account auxiliary consumers such air conditioning or heating. Furthermore, only few electric vehicles are yet available and test vehicles or prototypes do not reflect vehicles in mass production. Therefore a consistent modelling of the energy consumption of electric vehicles is undertaken, which allows for the variation of vehicle parameters and the consideration of different framework conditions. This approach – in contrast to the direct use of measurement data from different vehicles and drivers – also allows for good comparability of results, which is of special significance in a comparative LCA. Also scenarios for the further development of electric vehicles can be defined.

Methodology

The calculation of the energy demand for vehicle propulsion is based on a second-by-second speed profile. The physical energy demand at the wheel can be calculated for such a speed profile with defined vehicle parameters such as vehicle weight, front area as well as rolling resistance and air drag coefficients. However, despite the high energy efficiency of electric vehicles compared to conventional combustion engines, further energy losses in the drive train and at the engine have to be taken into account.

The “Tank-to-Wheel-Efficiency” (TtW-efficiency) is of special importance in a comparative analysis of the energy consumption of vehicles with different engine concepts. The TtW-efficiency is largely constant for electric vehicles, while considerable differences occur for combustion engines, depending on the speed profile. In urban areas, combustion engines often operate in partial load and thus with low efficiency. The fuel consumption of conventional vehicles is therefore mostly higher in urban areas compared to extra urban roads and motorways.

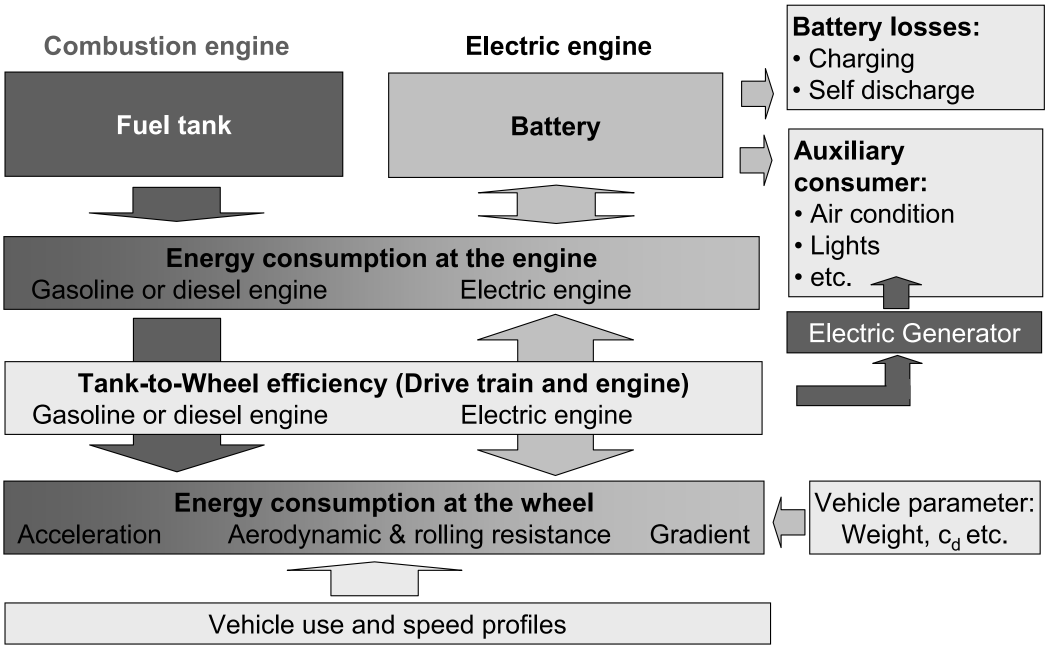


Figure 2: Energy flow in differentdrive train concepts

Battery Electric Vehicles (BEVs)

The vehicle parameters and TtW-efficiencies (Table), which are used for the electric vehicles in this paper, are largely based on the available literature and expert judgment. They are defined in order to represent an average compact car (e.g. Volkswagen Golf). Vehicle weights are based on (Öko-Institut, 2009), but rounded to a lower value to represent state of the art vehicles. Accordingly, a Plug-In Vehicle with 50 km electric range is assumed with a weight of 1500 kg and the full electric vehicle with a weight of 1600 kg. Similarly, front area and air drag coefficient are based on (Hausberger et al., 2009). The efficiencies of the electric energy chain are based on the available literature (Engel, 2007; Mazza and Hammerschlag, 2005; Weiss et al., 2000; Raskin and Shah, 2006; Kendall, 2008; Gielen and Simbolotti, 2005; Edwards et al., 2006; Garche, 2007).

The recuperation of braking power is calculated based on the energy loss in phases of negative acceleration, from which the natural breaking by rolling resistance and air drag have been subtracted. Additionally, it is assumed that 30% (see e.g. Guttenberg, 2004) of the kinetic energy is lost due to mechanical breaking. Afterwards, the same individual efficiencies as for propulsion (Table) are applied to the energy flow from the wheel to the battery and back to the wheel.

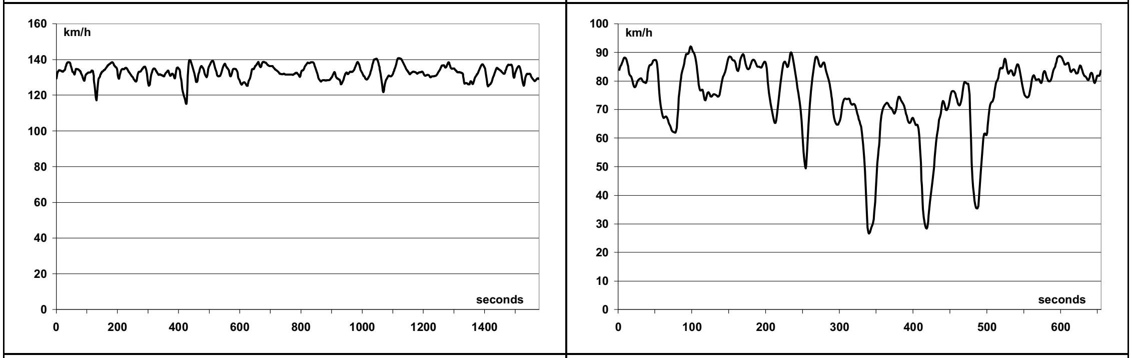
Table 1: Vehicle parameters and energy efficiency

Vehicle parameter	**Weight**	**Front area**	**Air drag coefficient**	**Rolling resistance coefficient**
PHEV-50	1500kg	$2m^2$	0,28	0,01
BEV	1600kg			
Efficiencies	**Charging**	**Battery**	**Engine**	**Drive Train**
Combined: 73%	90%	95%	90%	95%

Finally, also an assessment of the energy consumption of auxiliary consumers has been undertaken. It is based on a compilation of the average power demand of the common consumers (mainly Soltic, 2001; Wallentowitz and Reif, 2006 and Fabis, 2006) and estimates on their average use in summer and winter. The analysis resulted in an annual average power demand of about 1'000 Watts. In contrast to vehicles with combustion engines, electric vehicles will require additional heating in winter and partially also cooling for the batteries. In many cases, the use pattern of different consumers could only be estimated since no hard data have been available. The resulting power demand of 1’000 Watts should be regarded as an estimate for the annual average; temporarily, a much higher power demand may occur e.g. on hot summer days or cold winter days, when a lot of cooling or heating is required.

In order to consider a realistic driving profile, the traffic situations of the ‘Handbook Emission Factors’ (HBEFA) (INFRAS, 2010) are used. The different traffic situations are weighted according to the average traffic in Germany in urban areas, extra-urban areas and on motorways according to TREMOD (Knörr, 2010). 28 different traffic situations are taken into account, which have been recorded as part of extensive measurement programmes in real world traffic. The speed profiles of four selected driving cycles are presented in Figure 3. Using the driving cycles of the ‘Handbook Emission Factors’, the calculated values can also be compared to and complemented by the emission factors for conventional vehicles in TREMOD and HBEFA. This allows for the use of fuel consumption and pollutant emission factors from TREMOD and HBEFA for the reference vehicles.

Motorway (130 km/h) free flowing traffic | **Motorway (120 km/h) saturated traffic**



Urban (50 km/h) free flowing traffic | **Urban Stop and go traffic**

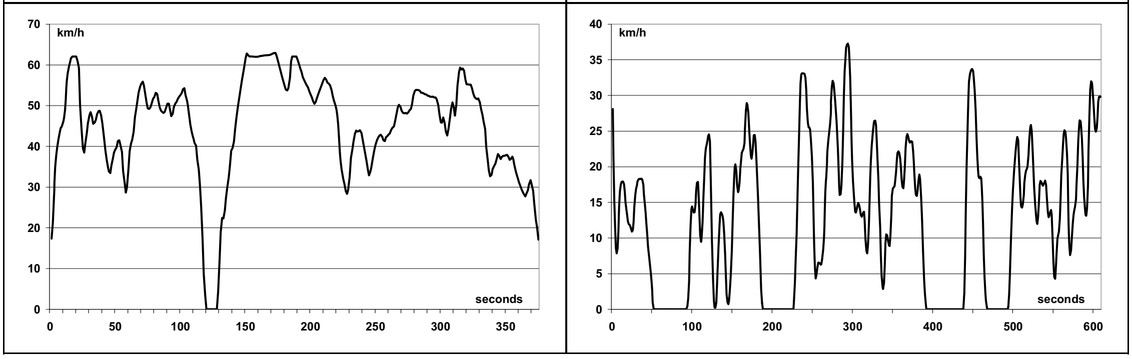


Figure 3: Speed profiles of selected traffic situations of the Handbook Emission Factors

Plug-In Hybrid Vehicles (PHEVs)

Due to the comparatively low energy density of batteries and thus limited driving range of ‘Battery Electric Vehicles’ (BEVs), also a ‘Plug-in Hybrid Electric Vehicle’ (PHEV) will be analysed. These vehicles combine the advantages of electric vehicles (high energy efficiency, regenerative breaking, charging from the grid) with the advantages of conventional vehicles, mainly the large driving range and possibility for fast refuelling. PHEVs are therefore regarded as an important short- to mid-term concept to open up the market for BEVs. PHEVs can be further distinguished by their electric driving range, which requires different battery capacities. In this paper, a PHEV -50 is considered which has a 50 km electric driving range.

Since PHEVs have two different engines they can either be operated in a dedicated mode (using only either the electric or the combustion engine) or a blended mode (using both engines at the same time either for reasons of power demand or energy efficiency). Not many data or information are yet available on the preferred driving mode for PHEVs as well as fuel consumption and pollutant emissions in blended mode. Different fleet tests are currently conducted which will allow a further insight into this complex topic. At this time, a pragmatic approach for an environmental assessment of plug-in hybrids is the assumption of dedicated operation only.

The 50 km electric driving range will cover most of the everyday trips which are assumed to be mostly in an urban area. The combustion engine in turn is assumed to be mainly used for longer distances, especially on motorways. Hence, the share of electric operation is assumed to be 90% in urban areas, 50% in extra urban areas and 10% on motorways. The differentiation of the electric mileage by road category is important due to the different efficiencies of electric and combustion engines in these traffic situations. Other vehicle parameters - except for the weight (see Table) - are assumed to be the same as for the BEV.

Electricity consumption in different traffic situations

Differentiated results for the specific electricity consumption of the defined BEV and PHEV-50 are presented in Figure . It can be seen, that the realistic energy consumption of a current electric compact car is in the range between 20 and 25 kWh/100km. In contrast to vehicles with combustion engines, energy consumption of the defined vehicle is lowest in urban areas (about 20 kWh/100km). This is due to the constantly high efficiency of electric engines, while the high fuel consumption of vehicles with combustion engines in urban areas is mainly due to the low engine efficiency in partial load. For electric vehicles in turn, the highest energy consumption occurs on a motorway.

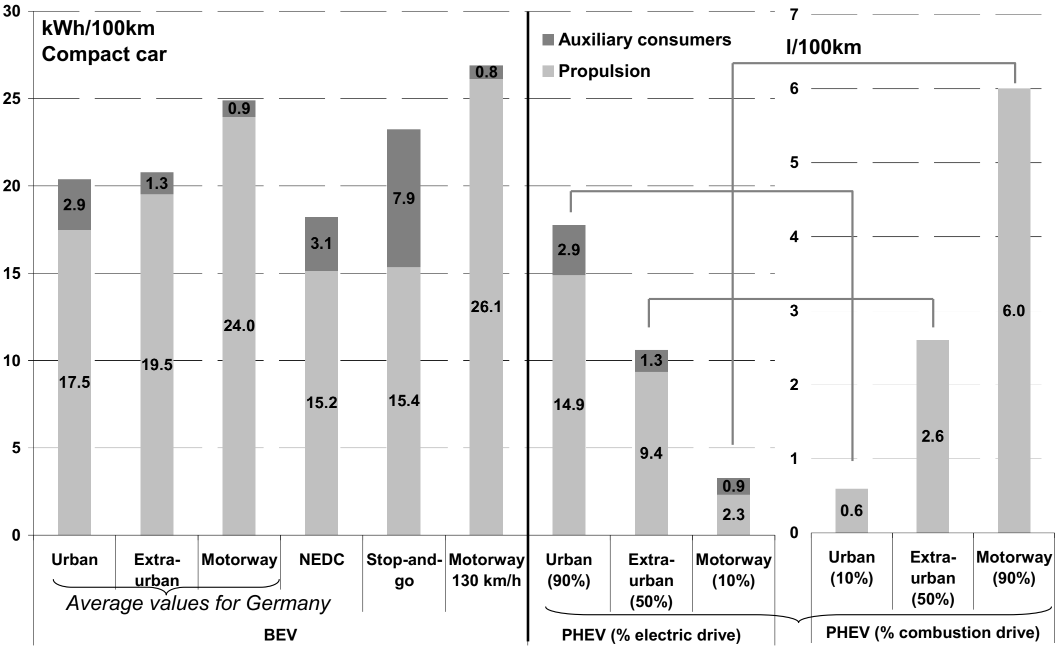


Figure 4: Electricity consumption of BEVs and PHEVs for different road categories

In addition to the average traffic situations in Germany, also the NEDC energy consumption has been analysed and is comparably low (about 18 kWh/100km) due to the less dynamic speed profile. The flexible modelling approach also allows for the analysis of defined traffic situations which can afterwards be grouped to specific use profiles if necessary. In stop-and-go traffic for instance (see Figure), energy consumption is about 15% higher compared to the urban average. Likewise on motorways, energy consumption in free flowing traffic with a 130 km/h speed limit is about 8% higher compared to the average motorway driving (which includes shares with lower speed limits).

The share of auxiliary consumers on total energy consumption differs significantly by road category. Auxiliary consumer energy consumption mostly depends on the duration of use, irrespective of the mileage driven during this time. The ‘per 100km’ average energy consumption is thus much higher in urban areas (14% of total energy consumption) compared to the motorway (4% of total energy consumption). Again it has to be noted, that the presented results are average figures and that the share of auxiliary consumers can be much higher temporarily, e.g. on hot summer days.

The presented electricity consumption of the PHEV is mainly influenced by the assumptions made for the share of electric drive and is complemented by an additional fuel consumption for the remaining share of combustion engine drive. Except for the slightly lower weight of the PHEV, all vehicle parameters are assumed to be the same for reasons of comparability. The energy consumption of auxiliary consumers is assumed to be taken directly from the battery.

Electricity generation for electric vehicles

Electricity for the operation of electric vehicles has to be supplied by a portfolio of power plants, whose composition is of major importance for the life cycle balance of electric vehicles. Though electric vehicles are counted as emission free in the framework of the EU legislation on CO_2 from passenger cars, this naturally does not correspond with the real situation in the energy sector.

The mix of power plants actually used for charging the vehicles is a function of economic framework conditions in the energy sector. Of relevance are the “merit order” of the power plants, the charging strategy (incentives for temporal flexibility), but also the possible consideration of an additional consumer segment “electric vehicles” in emissions trading.

Electric vehicles, as an additional electricity consumer, lead to the use of power plants which other wise would not have been used. As long as the diffusion of electric vehicles is limited, this concerns the load factor of existing power plants. In other words: already existing plants will increase their electricity production. The expected absolute electricity demand in a midterm perspective is limited: 1 million electric cars in Germany in 2020 would be an optimistic scenario and would lead to an electricity consumption of about 2 TWh – about 0.3% of today’s gross electricity consumption in Germany. In the long-run, however, also new capacities have to be built to meet the additional energy and - especially - capacity demands.

The plant actually used in a specific situation is determined by the so called merit order, which classifies the electricity production capacities according to operating costs. Several economic framework conditions determine the merit order, especially the price of fuels and certificates. Also the temporal distribution of the additional demand is of importance: Electricity demand is generally low at night, therefore marginal power plants will be those with lower variable costs (e.g. fuel costs) compared to marginal power plants during the day. At the same time, a smart charging strategy for electric vehicles (e.g. charging at night) leads to a better capacity utilisation. This can be an advantage for power plants with high capital costs, such as coal-fired power plants.

Not only the limited capacity of regional grids, but also the power requirement for electric vehicle charging calls for an intelligent charging strategy beyond conventional “plug-and-play” solutions. If one million electric vehicles would be charged at standard outlets at the same time, four large scale power plants would be necessary to meet this peak demand. Therefore flexible charging schemes are currently being developed, guided by variable electricity rates and so called ‘smart meters’. This way, electric mobility could support the integration of renewable energies into the power system with its combined battery capacity and a communication link to transmission grid and/or distribution network operators. The use of fluctuating energies (e.g. wind or solar power) can be significantly improved. In a long term perspective, the batteries of electric vehicles could also feed electricity back into the grid (‘vehicle-to-grid’ or ‘V2G’). Therefore, also the temporal distribution of vehicle charging has an influence on the mix of power plants to be considered for charging electric vehicles.

IFEU, in cooperation with other research institutes, currently undertakes a detailed modelling approach to analyse the interactions between mobility and electricity sector, including effects such as grid restrictions, emission trading, energy price elasticities and political constraints. Various scenarios will be investigated: a scenario without any constraints, i. e. no further restrictions with respect to charging time or electricity supply, a scneario including a smart charging strategy, where the daily charging tariff depends on the residual load (difference between fluctuating renewable electricity and grid load), and a scenario where additional renewable power plants are built as a consequence of the growth of electric vehicles. First results show that under the reference scenario, the electricity for charging vehicles is likely to be a mix of coal and gas fired power plants if no political initiatives are considered.

At this point, however, only a variation of possible power plant technologies can be presented:

- **Charging with the average electricity in Germany**: This applies if the additional electricity consumption of electric vehicles is considered to be too small to lead to any changes in the average electricity split.
- **Charging with old coal fired power plants (37% efficiency)**: Analyses show that such plants in many situations will be the marginal power plants.
- **Charging with a modern coal-fired or gas fired power plant**: Such plants could be built in the future to meet the additional demand from electric vehicles. They could also be the marginal power plants, if older plants already have been closed.
- **Charging with 100% renewable energies**: It is assumed that these are additional systems, i.e. that they would not have been built without the market penetration of electric vehicles. In this case, their low impacts can be credited to electric vehicles.

Electric vehicle life cycle emissions

First results of a comparative LCA are presented which are based on the discussed data. This means that the life cycle emissions of the defined BEV and PHEV will be compared to conventional gasoline and diesel reference vehicles. For this purpose, IFEU is currently developing an LCA model for electric vehicles called eLCAr (Electric Car LCA), using the software UMBERTO[1]. The following presentation of preliminary results will focus on greenhouse gases (CO_2-equivalents) and acidification (SO_2-euqivalents). The geographical reference is Germany and the results refer to the current or short term future situation. Functional unit is the life-time of a passenger car with different use patterns.

While BEVs are often assumed to be more suitable for urban areas due to their limited driving range, PHEVs can cover longer distances and are thus more suitable to replace passenger cars with mixed use. Results are therefore first presented for a BEV and PHEV with predominant use in urban areas (70% of the total mileage), with only a small share of extra urban (20%) and very little motorway driving (10%). These urban vehicles are assumed to have a limited life-time mileage of 120’000 km. Additionally a PHEV is analysed with the average use pattern of medium gasoline cars in Germany as considered in TREMOD (Knörr, 2010). This means 29% of the life-time mileage on urban roads, 39% on extra urban roads and 32% on motorways. As mentioned above, the PHEV in both cases is assumed to be mostly used in an electric mode (90%) in urban areas, on extra urban roads using both engines with equal shares (50% electric drive) and on motorways predominantly using the combustion engine (10% electric drive). The overall share of electric drive is thus different for the use patterns: While the average mixed use leads to share of 49% electric drive due to more extra urban and motorway driving, the urban use allows for a share of 74% electric drive.

An assessment is made for the vehicle production which is based on data for the Golf 4 in (Ecoinvent, 2008). For electric vehicles, the battery production is of special importance and thus considered in more detail. The assumed battery capacity is 25 kWh for the BEV and 12.5 kWh for the PHEV-50. The current mass balance of lithium ion batteries is based on (Ecoinvent, 2008). The energy demand stated therein, however, appears to be overestimated. Latest data (e.g. Sanyo, 2008) suggest a much lower energy consumption of battery production and is thus used as a reference for the results in this paper. Environmental impacts – especially from battery production – are expected to decrease in the future due to large scale production and increasing recycling rates. Data for this development are currently gathered as part of several IFEU research projects and will be integrated into eLCAr for future LCAs.

As reference vehicles, state of the art Euro 5 gasoline and diesel compact cars are defined. The fuel consumption is assumed in between the 2010 fuel consumption of small and medium car new registrations in TREMOD (Knörr, 2010). The PHEV is assumed to be equipped with a gasoline engine having the same fuel consumption as the reference car on extra urban roads and on motorways. Fuel consumption of the PHEV combustion engine on urban roads is - despite the higher weight - assumed to be 20% lower compared to the conventional vehicle, due to advantages such as recuperation and the avoidance of partial load.

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[1] http://ifeu.de/index.php?bereich=oek&seite=umberto

For NO_x emissions, the factors for Euro 5 vehicles from the latest version of the Handbook Emission Factors (INFRAS, 2010) are used. The difference in NO_x emissions between a conventional and a hybrid car can not be clearly determined. Available data show a lot of variability which can not easily be attributed to hybrid vehicle advantages. NO_x emissions are therefore assumed to be the same as for the conventional vehicles (see also (Schwingshackl, 2009)). Field tests currently being conducted will probably allow for a more differentiated and robust consideration of pollutant emissions from PHEVs.

Table 2: Fuel and electricity consumption values used in LCA

Vehicle	Urban areas	Extra urban areas	Motorway
Vehicle use (Urban)	70%	20%	10%
Vehicle use (Average)	29%	39%	32%
Gasoline car	7.5 l/100km	5.2 l/100km	6.7 l/100km
Diesel car	5.6 l/100km	4.0 l/100km	5.3 l/100km
BEV	20.4 kWh/100km	20.8 kWh/100km	24.9 kWh/100km
E-drive PHEV	90%	50%	10%
PHEV (Electricity)	17.8 kWh/100km	10.6 kWh/100km	3.3 kWh/100km
PHEV (Fuel)	0.6 l/100km*	2.6 l/100km	6.0 l/100km

* PHEV in urban area assumed to have 20% lower fuel cosumption than conventional vehicle

Results for life cycle greenhouse gas emissions based on the data and assumptions described in this paper are presented in Figure 5 and Figure 6. With predominant urban use and a limited life-time mileage (Figure 5), the BEV and PHEV using average German electricity lead to greenhouse gas emissions which are lower than for the gasoline car and slightly higher than for the diesel car. As expected, the highest contribution comes from the use phase, though especially for electric vehicles, also vehicle production (including the battery) is of relevance. This share of vehicle production is slightly lower for the PHEV due to the smaller battery. It has to be noted, however, that data for vehicle and battery production are considered to be more uncertain compared to the other values. Considering these uncertainties, life cycle emissions for a BEV and a PHEV using average German electricity in the described urban use profile are about comparable.

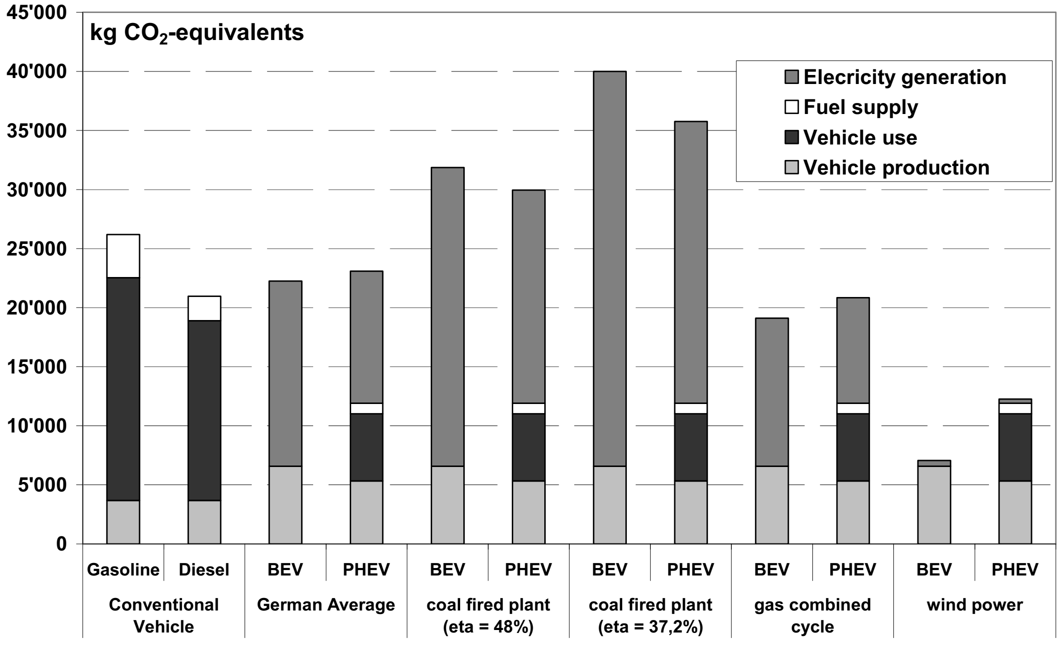

Figure 5: Life cycle greenhouse gas emissions of a compact car with different drive trains (120'000km ; 70% urban driving)

Greenhouse gas emissions increase significantly if coal fired power plants are used for charging the vehicles. The increase is less significant for the PHEV since they only partly use electricity. With coal fired power plants, life cycle emissions of BEVs and PHEVs are higher than for their conventional reference. Though also charging with a modern gas combined cycle plant may lead to a slight advantage over conventional vehicles, only the use of renewable energies - such as wind power - results in a significant reduction of life cycle greenhouse gas emissions.

Results for the PHEV with average mixed use and a life-time mileage of 150’000km are presented in Figure . The share of vehicle production is slightly lower due to the higher mileage. Greenhouse gas emissions are therefore slightly lower with average German electricity than for both conventional reference vehicles. Again emissions increase and are higher than for gasoline and diesel vehicles if coal fired power plants are used for charging. The benefits due to the use of renewable electricity are limited due to the lower share of electric drive, but still considerable.

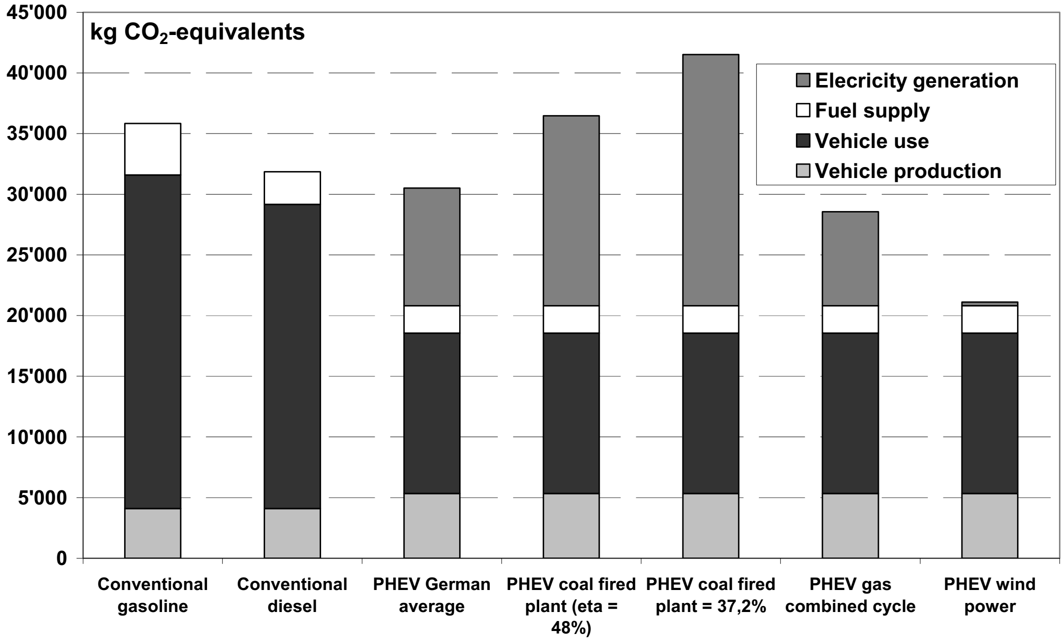

Figure 6: Life cycle greenhouse gas emissions of a conventional and plug-in hybrid compact car (150’000km; average mixed use)

Life cycle results for acidification (see Figure 7 and Figure 8) mostly show a similar pattern with the exception of conventional diesel vehicles. The fuel efficiency of these vehicles is contrasted by high NO_x pollutant emissions. However, future emission regulations (Euro 6) are expected to improve the NO_x balance of diesel cars.

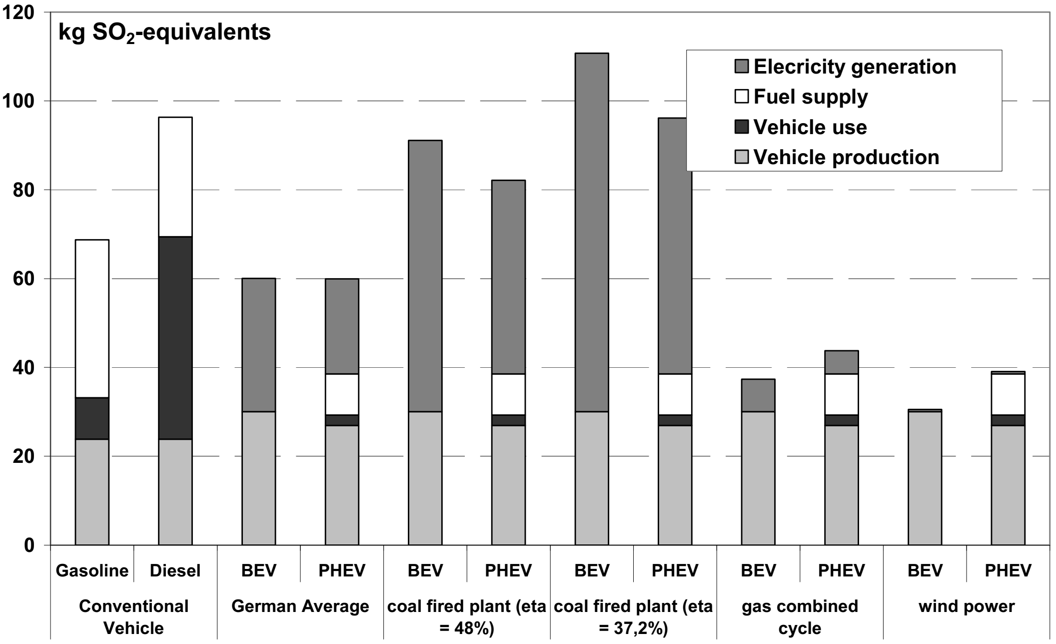

Figure 7: Life cycle acidification of a compact car with different drive trains (120.000km ; 70% urban driving)

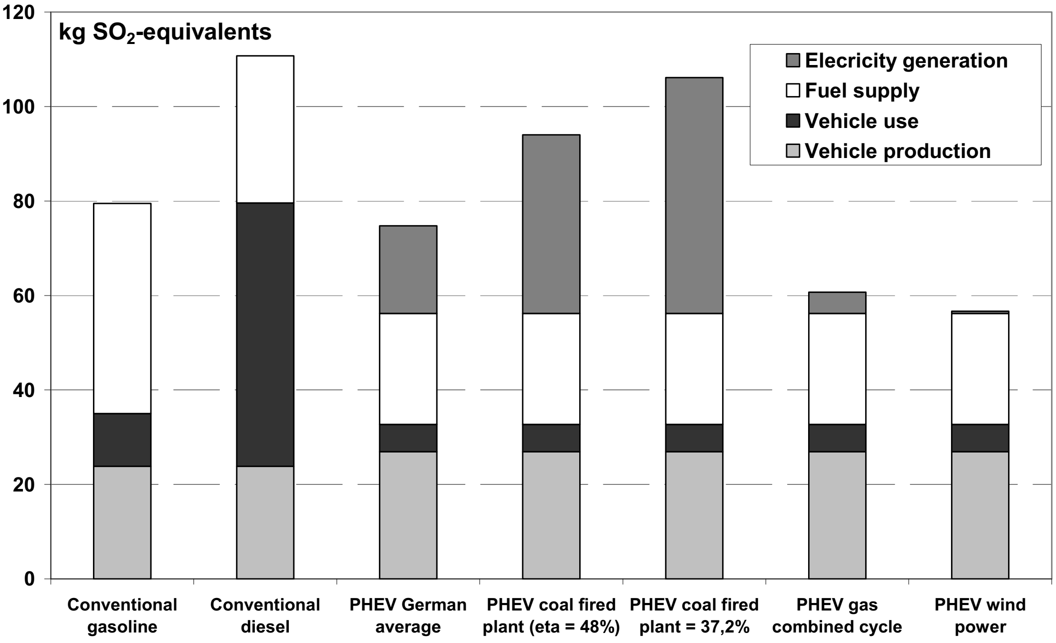

Figure 8: Life cycle acidification of a conventional and plug-in hybrid compact car (150'000km; average mixed use)

Conclusions

The presented results show, that electric vehicles charged with additional renewable energies lead to a significant improvement in the greenhouse gas balance, whereas other electricity sources lead to no substantial improvement or even higher life cycle emissions. Regarding acidification, the gasoline vehicle is comparable to electric vehicles using the German average electricity mix, whereas BEVs charged with coal fired plants lead to higher emissions. From an environmental point of view, it is therefore necessary that the market penetration of electric vehicles is based on the use of renewable sources.

In the discussion of GHG reductions with electric vehicles using renewable electricity, the question of additionality needs to be addressed. In countries with support schemes such as feed-in tariffs, many of the renewable power plants would be built anyway. Renewable energy systems should therefore only be credited to electric vehicles, if they are truly additional to the systems which are built based on the already existing legislation.

Hence, the question arises how renewable electricity systems can be solely allocated to electric vehicles. A real additionality of renewables requires further policital measures which need to be discussed. This may include not counting renewable electricity for electric mobility towards the renewable electricity and final energy targets as defined by the European Renewables Directive (EC, 2009) and national governments. Another approach securing more additionality of renewable electricity for electric mobility involves giving financial incentives (e. g. time-resolved tariffs) for load shifting based on the amount of fluctuating renewable energy (wind and solar) in the grid as well as based on grid restrictions due to wind feed-in. Thus, the use of the electric vehicle battery could enhance the capability of a system to integrate renewable electricity and thus contribute to additional renewable electricity. It is, however, essential, that such a smart charging strategy does not substantially increase the contribution of mid load power plants such as hard coal. A strong link of the tariff to renewable feed-in is necessary.

The methodological discussion also shows that life cycle emissions depend on a range of factors other than the electricity split, especially energy efficiency. Conventional vehicles are expected to further improve their environmental performance, also due to the EU CO_2 and pollutant emission legislation. Electric vehicles will therefore also have to further improve - not only for reasons of life cycle emissions, but in short term perspective also in order to achieve the highest possible driving range.

Besides the required propulsion energy, also the consumption of auxiliary consumers is significant. This applies even more to operation in urban areas, which is assumed to be preferable for electric vehicles due to the limited driving range. Thus also the energy consumption of auxiliary consumers will have to be paid further attention to. This includes energy efficient air conditions and possibly alternative (e.g. fuel based) heating system.

The methodology and data base will be further developed in order to improve and further differentiate the results. Such an in depth analysis of electric mobility is important in order to address advantages and disadvantages at an early stage and thus realise the full environmental potential of electric mobility. Overall, electric vehicles offer some promising mid- to long-term perspective in reducing environmental impacts of road transport.

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